ELASTIC SCATTERING OF Λ HYPERONS AND K_1^0 MESONS ON HYDROGEN

B. A. ARBUZOV, E. N. KLADNITSKAYA, V. N. PENEV, and R. N. FAUSTOV

Joint Institute for Nuclear Research

Submitted to JETP editor November 5, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 979-984 (April, 1962)

The elastic scattering of Λ hyperons and K_1^0 mesons on protons is investigated. The elastic scattering cross sections are estimated on the basis of 20 detected cases of the reaction $\Lambda + p \to \Lambda + p$ and 16 cases of the reaction $K_1^0 + p \to K_1^0 + p$. The angular distributions of the scattered particles and the momentum distributions of the particles before scattering are described. Experimental data on the scattering of Λ hyperons, having momenta in the interval from 500 to 1500 MeV/c, is compared with theoretical calculations.

UP to now only one experimental article,[1] in which data on two inelastic and four elastic scattering events are cited, has been devoted to Λ hyperon-nucleon scattering.

In the present work an attempt is made to investigate the elastic scattering of Λ hyperons and K_1^0 mesons on protons. Λ and K_1^0 particles, produced in the interaction of 7 to 8 BeV/c π^- mesons with hydrogen and carbon in a propane bubble chamber[2] located in a constant magnetic field of intensity 13,700 Oe, were utilized.

SCANNING OF PHOTOGRAPHS AND SELECTION OF EVENTS

Altogether, 70,000 photographs were scanned. All photographs were scanned twice, one time merely for the discovery of elastic scattering events involving Λ and K_1^0 particles. The efficiency of detecting the requisite events was found to equal 81%. After processing the results of the measurements, 20 cases were selected (see Fig. 1, a, b) in which a V^0 particle moving away from a scattering point was identified as a Λ particle and for which the following conditions were fulfilled within the error limits of the momentum and angle determinations: a) coplanarity of the directions of flight of the Λ hyperons (before and after scattering) and of the recoil proton b) equality between the transverse (with respect to the direction of motion of the Λ before scattering) momentum of the Λ after scattering and the transverse momentum of the recoil proton; c) equality of the energy of the particles before and after scattering. Sixteen events involving the elastic scattering of K_1^0 mesons on hydrogen* were selected in analogous fashion. On the average, the errors in the determination of particle momenta amount to 10—15%; in the determination of scattering angles and noncoplanarity, they amount to 1—1.5°.

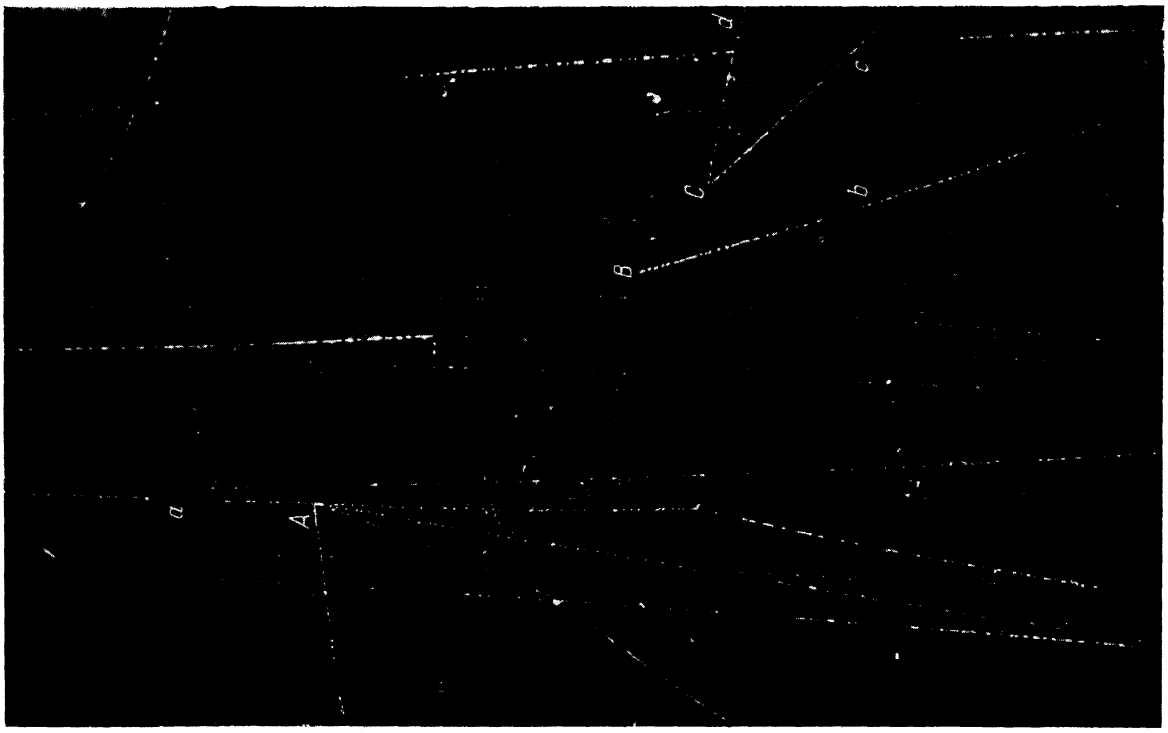
An estimate was made of the contribution due to reactions which might, under certain conditions, imitate the elastic scattering of Λ and K_1^0 particles (false reactions). For example, the reactions

$$n + p \to \begin{cases} p + K^0 + \Lambda\,(\Sigma^0) \\ n + K^+ + \Lambda\,(\Sigma^0) \end{cases} \tag{1}$$

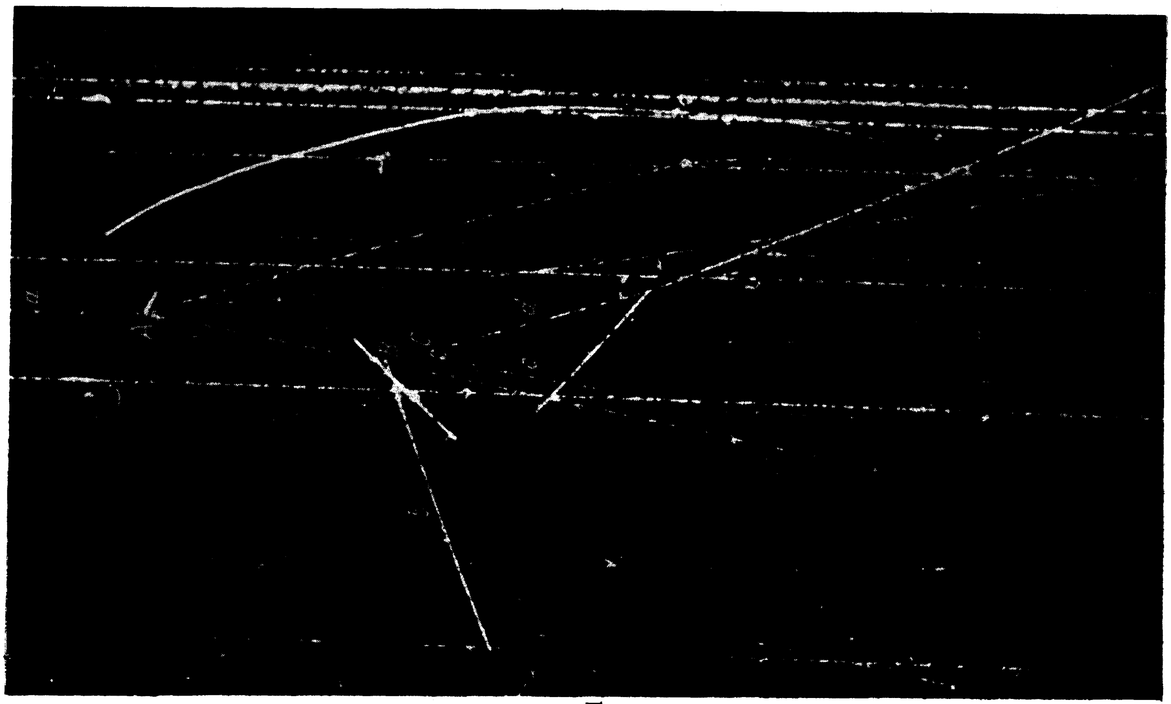
can be false (i.e., they might be mistakenly identified as elastic scattering processes) in those cases when the Λ decays inside the chamber, it is impossible to distinguish the K^+ from a proton, and the neutral K^0 or n particles carry away a small amount of energy (the K^0 decays outside the chamber). Assuming that the cross section for the production of strange particles in np collisions does not exceed 0.2 mb,[3] we found that reactions of type (1) must be observed not more than 10 times in 70,000 photographs. The momentum spectra of the neutrons and K^0 mesons from reactions (1), calculated according to the statistical theory, have such shape that only 2% of all Λp scattering events can be contamination due to reactions (1).

The contamination due to the reaction

*All scattered Λ hyperons and K_1^0 mesons were produced inside the chamber. Eight Λ hyperon scattering events and 5 K_1^0 meson scattering events were found in which the particles were created outside of the chamber. These events are indicated on the graphs by a dotted line; however, they were not taken into account in the calculation of cross sections.



a



b

FIG. 1. Examples of events involving the elastic scattering of strange particles on protons: (a) Λ hyperons, (b) K_1^0 mesons. The Λ or K_1^0 mesons are created at point A; their collision with protons takes place at point B (b indicates the track of the recoil proton); the Λ or K_1^0 particles decay at point C.

$$\Lambda + p \rightarrow \widetilde{K}^0 + n + p \qquad (2)$$

can be neglected, if one bears in mind the large threshold energy of the Λ particle which is necessary for this reaction, and also the spectrum of neutrons after the reaction. The recoiling particles in the selected elastic scattering events acquired, on the whole, momenta smaller than 1.2 BeV/c and were reliably identified, according to ionization, as protons. Therefore the contamination due to reactions of the type

$$\underline{\widetilde{K}^0 + p \rightarrow \Lambda + \pi^+},$$
$$K^0 + p \rightarrow K^0 + \pi^+ + n, \qquad \Lambda + p \rightarrow \Lambda + \pi^+ + n \qquad (3)$$

does not exceed 10% of the separated events.* The kinematics of the reaction

$$\widetilde{K}^0 + (n, p) \rightarrow \Lambda + p \qquad (4)$$

differ markedly from the kinematics of elastic scattering; consequently, this reaction will not give rise to false Λp scattering events.

The probability of the accidental appearance of a combination of particles imitating elastic Λp or $K_1^0 p$ scattering was calculated. It was found to equal 1.2×10^{-9} per frame. This probability is considerably larger for events involving the elastic scattering of the Λ or K_1^0 particles which were created outside of the chamber; in this case the probability equals 1.6×10^{-5} i.e., 1 or 2 of the events which were identified as elastic scattering of Λ or K_1^0 particles (which were created outside of the chamber) are false. An integral distribution of the Λ hyperons with respect to their time of flight after scattering was constructed. It indicates that there were no substantial systematic omissions of events.

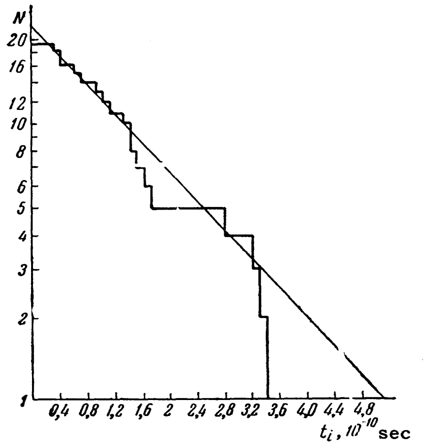


FIG. 2. Integral distribution of Λ hyperons (which were scattered on protons) with respect to time of flight.

*This possible contamination has been taken into consideration in estimating the respective cross sections.

CROSS SECTIONS. ANGULAR DISTRIBUTIONS

The cross sections for the production of strange particles in $\pi^- p$ collisions [4] were used to determine the current of Λ and K_1^0 particles. The average ranges of Λ and K_1^0 particles inside the chamber were determined according to the ranges up to decay of 325 identified Λ hyperon events and 590 K_1^0 meson events. They respectively are $\bar{l}_\Lambda = 5.09$ cm and $\bar{l}_{K_1^0} = 6.12$ cm. For Λ or K_1^0 particles which avoided being detected in the chamber, the average range is taken equal to the average potential length of the Λ or K_1^0 particles which were detected: $\bar{L} = 21.69$ cm. Λ hyperons and K_1^0 mesons decaying into "neutral channels," and also K_2^0 particles, were not considered. The cross section for the production of Λ and K^0 particles on carbon is taken to be proportional to $A^{2/3}$, which is in good agreement with our preliminary results for the Λ hyperon production cross section on carbon.

The number of elastic Λp and $K_1^0 p$ scattering events was determined taking into account corrections for the probability of detecting Λ and K_1^0 particles after scattering in the effective volume of the chamber and for scanning efficiency. The systematic omission of events with slow (~ 150 MeV/c) recoil protons sets limits on the detection of scattering events for small angles ($< 18°$ for Λ hyperons and $< 12°$ for K_1^0 mesons in the center-of-mass system, the average momentum of the incoming particle being 1 BeV/c).

An estimate of the number of events which involve the scattering of Λ hyperons and K_1^0 mesons on quasi-free protons of carbon [Λ(p) scattering] was made in the same way as in the work by Stannard, [5] devoted to an investigation of the elastic scattering of $\Sigma^\pm$ hyperons on hydrogen in a propane bubble chamber. Recognizing that the error in Λ-hyperon scattering angle amounts to 1.5° in our case and the error in the K_1^0 scattering angle is approximately 1°, it appears that contamination from Λ(p) scattering amounts to 10% of all elastic Λp scattering events, and contamination from K_1^0(p) scattering comprises 7% of the elastic $K_1^0 p$ scattering events. Taking the indicated corrections into account, the cross sections for elastic scattering of Λ and K_1^0 particles on hydrogen, averaged over the total momentum spectrum (Fig. 3, a, b), are given by

$$\sigma(\Lambda + p \rightarrow \Lambda + p) = 36 \pm 14 \text{ mb},$$
$$\sigma(K_1^0 + p \rightarrow K_1^0 + p) = 22 \pm 9 \text{ mb}.$$

Utilizing the momentum distribution of Λ particles created in $\pi^- p$ collisions (Fig. 3, a) and

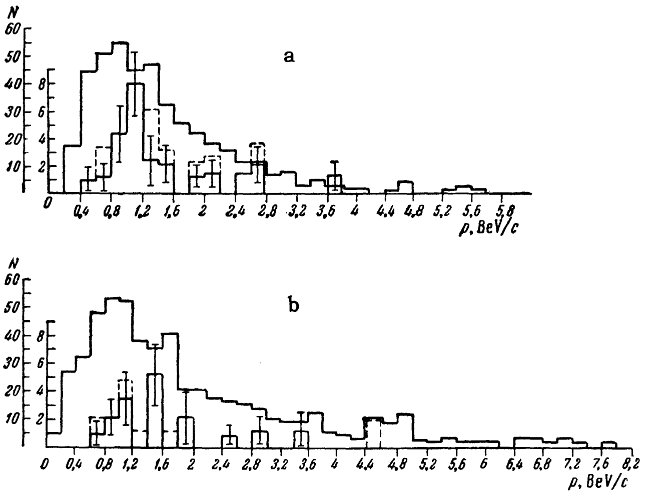


FIG. 3. Momentum distributions (in the laboratory coordinate system) of Λ hyperons and K_1^0 mesons for (a) elastic Λp scattering events and (b) for elastic K_1^0p scattering events. The left scale pertains to the upper histograms of Λ hyperons and K^0 mesons, respectively, which were created in πp collisions. The right scale is given for Λp and K_1^0p scattering events, respectively.

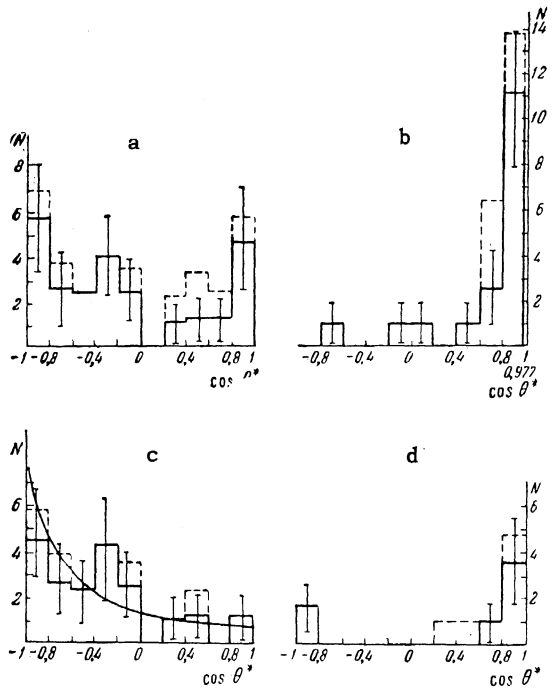


FIG. 4. Angular distributions of strange particles in the center of mass system: (a) Λ hyperons scattered on protons, (b) K_1^0 mesons; (c) Λ hyperons having momenta before scattering of 0.5 to 1.5 BeV/c; (d) Λ hyperons having momenta before scattering > 1.5 BeV/c. A theoretical curve, based on the model of peripheral collisions with exchange of scalar K particles, is plotted in Fig. (c).

also preliminary data obtained in our group about Λ hyperon production in π^-C collisions, it is possible to estimate the Λ particle elastic scattering cross sections, averaged over smaller intervals of the momenta of the scattered particles: $\sigma_1 = 42 \pm 16$ mb in the interval from 0.4 to 1.5 BeV/c (average momentum 1 BeV/c), $\sigma_2 = 30 \pm 15$ mb in the interval from 1.5 to 2.5 BeV/c (average momentum 2 BeV/c).

The angular distributions of Λ hyperons and K_1^0 mesons in the center-of-mass system are shown in Fig. 4. Apparently the K^0 mesons produce an abrupt maximum in the forward scattering (Fig. 4, b). In the angular distribution of Λ hyperons, Λ particles traveling backwards predominate (Fig. 4, a). If the momentum of the scattered Λ hyperons has an upper limit, the distribution becomes more anisotropic: out of 16 hyperons having momenta less than 1500 MeV/c in the laboratory system, 13 were moving backwards after scattering and 3 were moving forwards. These values are presented without correction for detection efficiency.

DISCUSSION

π-meson and K-meson forces can give a contribution to the elastic ΛN scattering. Neither the π meson pole nor the exchange of two π mesons in the resonant T = 1, J = 1 state are present in this case. Elastic Λp scattering with exchange of π mesons was considered by de Swart and Dullemond.[6] Utilizing the "global" symmetry hypothesis for Λ particles with energy up to 270 MeV, the authors obtained a total cross section of 30—40 mb and an angular distribution with predominant forward scattering of the Λ hyperons. Thus, even allowing for loss of part of the Λp scattering events at small angles (up to 18° in the c.m.s.), the angular distribution (in the c.m.s.) of the Λ hyperons, obtained on the basis of the hypothesis concerning the exchange of π mesons between the Λ particle and the proton in an elastic scattering process, is not in agreement with the experimentally obtained distribution.

Since the momentum transfer from the proton to a 1.5-BeV/c Λ hyperon is on the whole small (up to 600 MeV/c), it is natural to consider a model of peripheral collisions involving the exchange of a strange particle with T = ½ (Fig. 5). Experiments on the scattering of Σ particles on protons[5] also indicate the importance of a calculation of such an exchange. We consider the contribution to elastic scattering of Λ hyperons

FIG. 5

which is dependent on the exchange of a K or K′ meson for different parities and spins of these particles. Calculations of such interactions were carried through for 1 BeV/c (in the laboratory system) Λ hyperons. In the case of a pseudoscalar K meson the angular distribution in the c.m.s., as the calculations indicate, must be asymmetrical: Most of the hyperons must emerge in the forward direction. The total cross section obtained is $\sigma = 0.1\,(g_p^2/4\pi)^2$ mb.

In the presence of scalar K meson exchange, a strong asymmetry in the angular distribution of the Λ hyperons should be observed with preferred emergence backwards in the c.m.s., and the total elastic cross section for the scattering of Λ hyperons on protons must be $\sigma = 24\,(g_s^2/4\pi)^2$ mb. In this case both the angular distribution and the total cross section (assuming the coupling constant $g_s^2/4\pi \sim 1$) are in agreement with the experimental results obtained in the present work.

In the case of K′ exchange, the cross section has a much weaker angular dependence, which is related to the larger value of the K′ mass.[7] In this connection, the cross sections for cases of vector and scalar couplings (i.e., the exchange of vector and scalar K′ mesons) respectively amount to

$$\sigma_V = 7\,(f_V^2/4\pi)^2 \text{ mb}, \qquad \sigma_S = 5\,(f_S^2/4\pi)^2 \text{ mb}.$$

Utilizing the data on the reaction $\pi^- + p \to \Lambda + K^0$, it is possible to estimate[8] the coupling constants for the interaction of a K′ particle with nucleons and Λ hyperons:

$$f_V^2/4\pi = 0.3 - 0.5, \qquad f_S^2/4\pi = 5 - 10.$$

For these values of the coupling constants, the values of the total cross sections do not agree with the experimental results.

Thus, of the versions considered, the scalar K meson exchange hypothesis gives the best agreement with experimental results for the scattering of Λ particles on hydrogen. Shalamov et al[9] arrived at a similar conclusion by analyzing the process $\pi + N \to \Lambda + K + \pi$. However, this hypothesis is in contradiction with experiments in which the K meson behaves, to all appearances, like a pseudoscalar particle.[10] It is possible to remove this contradiction if nonconservation of parity is assumed in the ΛNK interaction, i.e., if one takes in this interaction a mixture of scalar and pseudoscalar couplings. A similar hypothesis was considered in the article by Blokhintsev and Wang.[11] For agreement with experiment (under the condition that the exchange goes via a pseudoscalar K meson), it is necessary to assume that a large contribution from nonpole diagrams exists.

In conclusion the authors express their gratitude to Academician V. I. Veksler for his constant interest in the work and for fruitful discussions, to N. M. Viryasov, I. Vrana, Kim Khi Ying, A. A. Kuznetsov, A. K. Mikhul, Nguyen Dinh Tu, A. V. Nikitin, and M. I. Solov'ev for help in the selection of events and for consideration of the results, to the group of research workers for carrying out the necessary measurements, and to coworkers at the computing center for making the calculations on electronic computers.

Note added in proof (March 12, 1962). After the article had already been sent to the printer, we were informed about the article by Brown et al [Phys. Rev. Letters 7, 346 (1961)] with data on 14 cases of elastic scattering of Λ hyperons on hydrogen in the momentum interval from 400 to 1000 MeV/c (in the laboratory system).

[1] Crawford, Cresti, Good, Solmitz, Stevenson, and Ticho, Phys. Rev. Letters **2**, 174 (1959).

[2] Wang, Solov'ev, and Shkobin, PTÉ No. 1, 41 (1959), Instruments and Experimental Techniques No. 1, 43 (1959).

[3] Louttit, Morris, Rahm, Rau, Thorndike, Willis, and Lea, Phys. Rev. **123**, 1465 (1961).

[4] Wang, Wang, Veksler, Vrana, Ting, Ivanov, Kladnitskaya, Kuznetsov, Nguyen Dinh Tu, Nikitin, Solov'ev, and Ch'eng, JETP **40**, 464 (1961), Soviet Phys. JETP **13**, 323 (1961).

[5] F. R. Stannard, Phys. Rev. **121**, 1513 (1961).

[6] I. I. de Swart and C. Dullemond, VYO-9746, preprint.

[7] Alston, Alvarez, Eberhard, Good, Graziano, Ticho, and Wojcicki, Phys. Rev. Letters **6**, 300 (1961).

[8] Chia-Hwa Chan, Phys. Rev. Letters **6**, 383 (1961).

[9] Shalamov, Shebanov, and Grashin, JETP **40**, 1302 (1961), Soviet Phys. JETP **13**, 917 (1961).

[10] Block, Brucker, Chang, Gessaroli, Kikuchi, Kovacs, Meltzer, Pevsner, Schlein, Strand, Cohn, Harth, Leitner, Monari, Lendinara, and Puppi, Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester (Interscience Publishers, New York, 1960), p. 419.

[11] D. I. Blokhintsev and Wang Yung, Nuclear Phys. **22**, 410 (1961).

Translated by H. H. Nickle
161